Strategic Plan

for the

Joint Center for Satellite Data Assimilation

FY 2007-2012

Vision

A weather, ocean, climate, and environmental analysis and prediction community empowered to effectively assimilate increasing amounts of advanced satellite observations from the evolving Global Earth Observing System of Systems (GEOSS)

Table of Contents

A Message from the Director

Effective environmental prediction depends on a number of critical elements. Accurate, timely, and well-distributed observations of the state of the Earth's environment comprise one of these elements. Effective and sophisticated algorithms and techniques for the quality control and analysis of these observations are another. Models that embody the physical and chemical laws governing the behavior of the Earth's land surface, oceans, and atmosphere, and computers with the power to run these models rapidly enough to make timely predictions are also essential elements of an effective environmental analysis and prediction system.

The science of data assimilation is the mortar that binds these elements into successful prediction systems. Modern satellite sensors provide observations with an accuracy, coverage, and resolution essential for this data assimilation task. The Joint Center for Satellite Data Assimilation (JCSDA) is dedicated to efficiently developing, in a coordinated fashion, improved satellite data assimilation capability in operational agencies in the United States.

This activity is best done on a coordinated multi-agency basis, as the common development work necessary to assimilate these billions of satellite observations each day can be partitioned and shared to avoid needless duplication across the agencies. It also allows the Center to draw on the extensive scientific expertise that is available in the partnering agencies and their University collaborators.

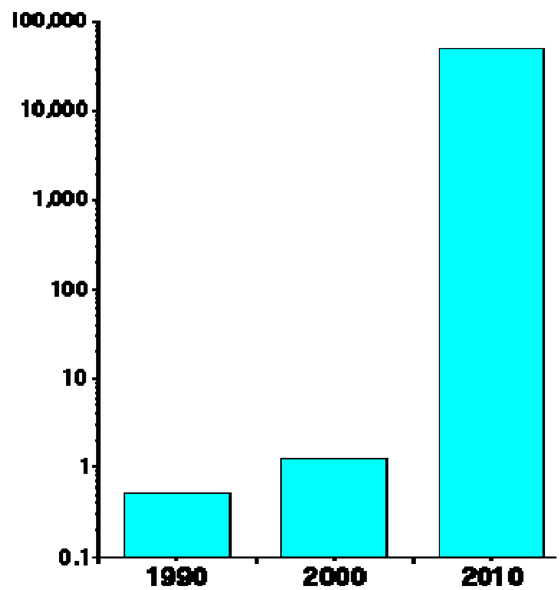
The importance of satellite data assimilation to successful environmental prediction cannot be overstated. Successful environmental prediction is vital to the safety, security, and economic well being of the nation and its citizens.

John Le Marshall, PhD
Director, JCSDA

Background

The nation has a continuing need for more accurate environmental analyses and forecasts. As a result of a growing population, burgeoning development in coastal areas, an expanding economy, the prospect of global climate change, dependence of military operations on environmental conditions, and threats to homeland security, the United States is more vulnerable than ever to environmental phenomena. As a result of improved environmental satellite observations and more effective use of these data in analyses and forecasts, together with advances in modeling and computational power, dramatic progress has been made over the past few decades in the timeliness, accuracy, and range of weather forecasts and in understanding and predicting climate variations.

The JCSDA was established to improve and accelerate the use of research and operational satellite data in numerical weather, ocean, and climate analysis and prediction. Its establishment was motivated by three factors:



- The United States and other international partners are launching new satellites that will dramatically increase the quality and quantity of space-based environmental data. The number of environmental satellite measurements is expected to jump by five orders of magnitude over the next ten years.
- Satellite data comprise 99 percent of all observations received by operational weather and climate prediction centers. However, many types of observations are not fully utilized due to inadequate scientific development.
- An increased and more focused national effort is required to accelerate scientific progress for both current and future observations. Common algorithms will accelerate satellite data use among the major operational and research, weather and climate prediction centers.

The JCSDA provides a focal point for the development of common software and infrastructure for the partner agencies--National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense (DoD). This partnership allows these agencies to fully prepare for the upcoming flood of data from the advanced satellite instruments to be launched during the next five to ten years and to better achieve their mission goals. JCSDA research and development directly supports NOAA and DoD in their operational environmental prediction responsibilities at home and abroad, and. NASA in understanding the Earth’s climate and in transferring its research to operational weather and climate forecasting.

The JCSDA Partners

National Oceanic and Atmospheric Administration
National Aeronautics and Space Administration
Department of Defense

Our Mission

To accelerate and improve the quantitative use of research and operational satellite data in weather, ocean, climate, and other environmental analysis and prediction systems

This is a substantial undertaking given the hundred-thousand-fold increase in satellite data anticipated this decade from nearly 50 new instruments

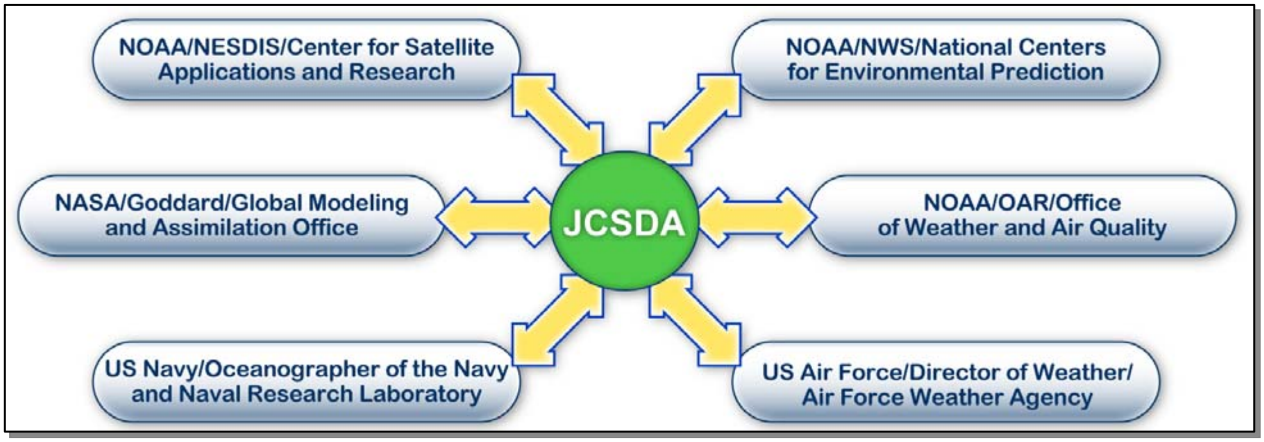
Benefits to the Nation

Through its mission to increase and improve the use of satellite observations in analyses and forecasts, the JCSDA ensures that the nation obtains the best return in improved environmental prediction from its large investments in new satellites and instruments. The impacts of poorly forecasted environmental phenomena are costly both in lives and dollars. As much as $4 trillion of the nation's $10 trillion economy is affected by weather and climate events each year. More accurate and longer range environmental forecasts directly affect the ability of our populace to prepare for weather events, climatic fluctuations, and air pollution episodes, allowing protective actions to be taken to mitigate their effects. Better forecasts help businesses plan better and promote safer and more efficient transportation. More accurate forecasts for DOD and homeland security increase the safety and effectiveness of our defense forces throughout the world and better protect the home front from terrorist release of chemical, biological, or radioactive agents into the atmosphere.

Modern-day environmental prediction is based on the use of numerical (computer-based) forecast models of weather, ocean, climate, and environmental hazards. The vast majority of the observations feeding such models come from environmental satellite observations, and these data are particularly important in many data-sparse areas of the world where DOD operates. By optimizing the use of these data, the JCSDA accelerates overall improvements in environmental prediction. Such improvements increase the level of detail and extend accurate weather forecasts further into the future, enabling longer lead times to prepare for floods, hurricanes, and other severe weather events. They also permit more accurate sea state and air quality forecasts, increase the accuracy of seasonal to inter-annual climate predictions, add to knowledge of long term climate variations, and facilitate detection and prediction of hazardous environmental conditions.

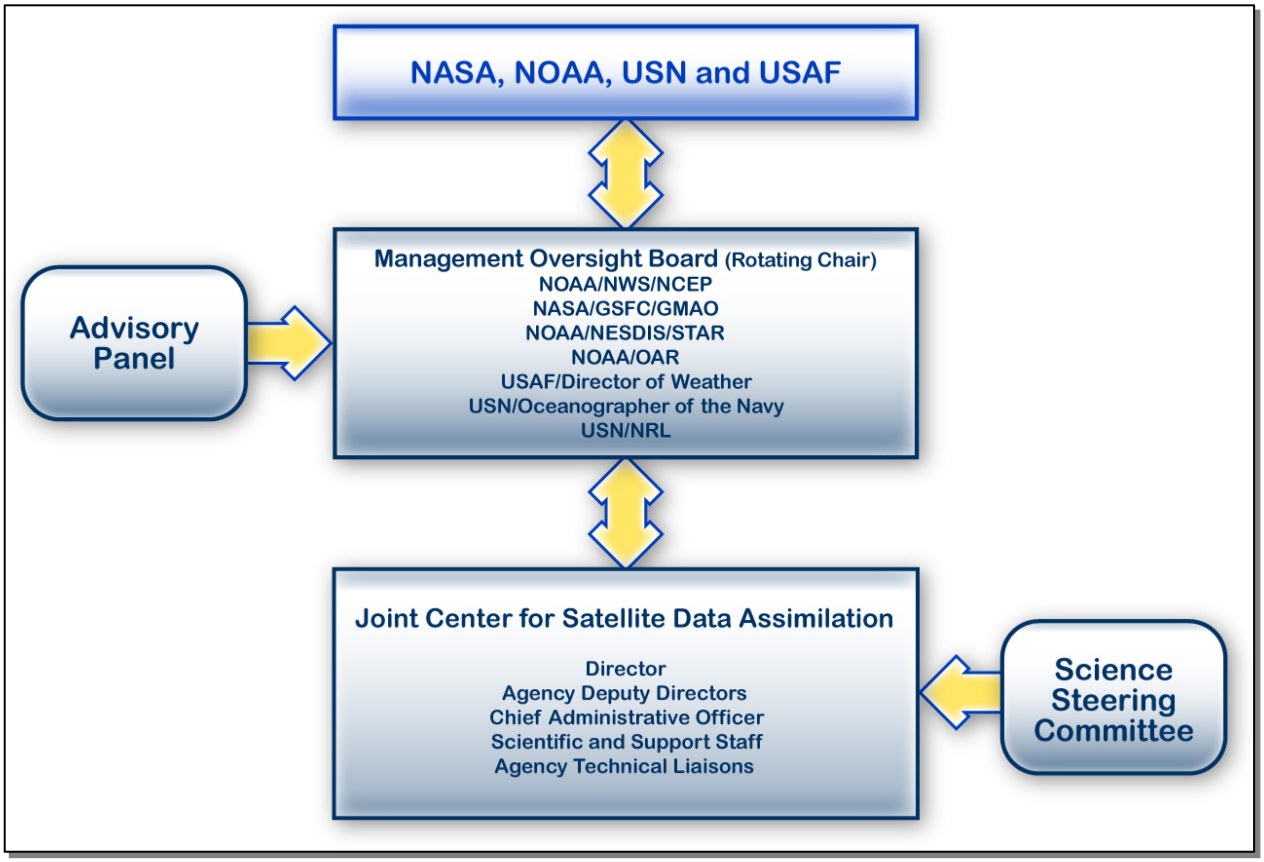
JCSDA Partners

The key to the JCSDA's success is the partnership in which the resources and talents of NASA, NOAA, and DoD are combined to solve problems of mutual interest.



- NASA performs research and development to understand and protect our home planet. NASA's Earth science research program improves weather, climate and environmental forecast duration and reliability by new space-based observations, assimilation, and modeling. In collaboration with its JCSDA partners, NASA Goddard's Global Modeling and Assimilation Office develops world-class data assimilation systems to maximize satellite data utility and to generate analysis products in support of NASA instrument teams and other scientific research.
- NOAA's mission is to understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs.
  - NWS/NCEP analyzes global environmental information and generates a wide variety of environmental analyses, forecasts, guidance information and products.
  - NESDIS/STAR conducts research and develops new satellite products to improve and expand the use of satellite data for monitoring global meteorological, climatological and environmental conditions.
  - NOAA/OAR, the research arm of NOAA, anticipates the science and technology needed by the nation's operational forecasting services in the next ten years.
- DoD develops and applies environmental science and technology to enhance effectiveness of sensors, weapons systems, and global military operations, ranging from humanitarian relief to winning the nation's wars.
  - NRL performs basic research and development and transitions systems for atmospheric and ocean data assimilation; multiscale numerical prediction; nowcasting, and remote sensing.
  - Oceanographer of the Navy supports the FNMOC/NAVO production centers, which generate tailored products that maximize the combat effectiveness of our Navy/Marine Corps seafaring and expeditionary forces.
  - AFWA generates tailored operational products that support the Air Force and Army warfighting mission, maximizing our nation's aerospace and ground combat effectiveness.

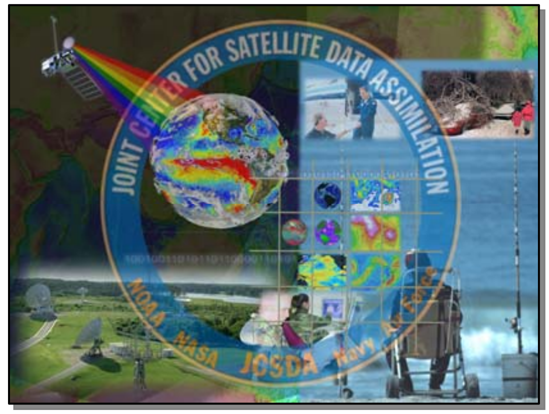
JCSDA Structure



Project scientists at the JCSDA partner agencies and extramural community are the foundation of the Center's activities. They submit proposals in response to annual guidance on the JCSDA's research and development priorities. The Technical Liaisons from the partner agencies and external reviewers screen the proposals to select those projects expected to have the greatest impact on achieving the Center's goals. The entire development program is managed and coordinated by the JCSDA Management. JCSDA Management reports to the Management Oversight Board, which facilitates and sustains cooperation between the sponsoring institutions, and reviews and approves the policies, research, operational themes, priorities, and annual JCSDA Technical Operating Plan (JTOP), its budget, and its management. Two external panels review and guide JCSDA activities. The Advisory Panel provides high level strategic guidance to the Management Oversight Board on all activities of the JCSDA. The Science Steering Committee reviews the JCSDA scientific priorities and research and development program annually and provides a report to the JCSDA Director.

JCSDA Cross-Cutting Goals

The JCSDA has adopted three cross-cutting goals to achieve its vision:



1. Reduce from two years to one year the average time for operational implementation of new satellite technology.

   Satellites have limited lifetimes (about five years). By reducing the time from launch to data utilization from two years to one year, the nation would realize a 33 percent increase in productivity per satellite. By assimilating the data sooner, advances in environmental analyses and forecasts would be accelerated.

2. Improve and increase the use of satellite data in environmental analysis and prediction systems

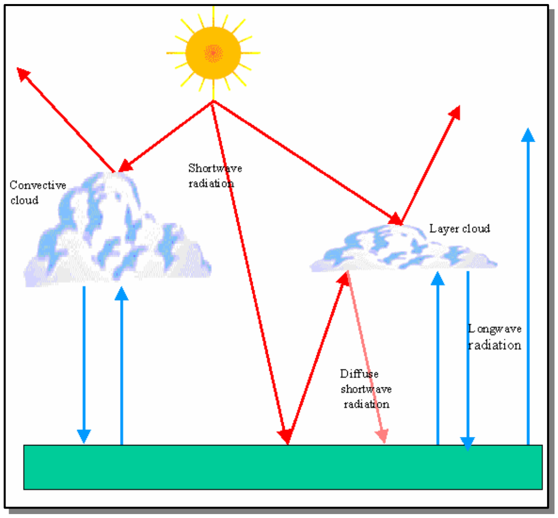
   Substantial amounts of current satellite observations are not assimilated in environmental analyses and prediction systems, and certain satellite observations are not assimilated as effectively as they could be. There are disparities in the use of satellite observations by application: the use of satellite data for atmospheric data assimilation outpaces its use in climate, ocean, land, and atmospheric chemistry data assimilation. Achievement of this goal requires development of data assimilation systems for more effective use of cloud and precipitation observations and for better handling of the time varying nature of observations.

   This cross-cutting goal also includes use of satellite data in climate analysis and prediction. For example, assimilation of inter-calibrated satellite observations in reanalyses to produce better modern-era climate data records and validating climate models with satellite observed radiances and products derived from multiple sensors.

3. Assess the impacts of data from advanced satellite instruments on environmental analyses and prediction systems

   The costs for developing, building, launching, and operating new satellite instruments are substantial. Prior to making such investments, it is necessary to quantify the potential benefits of the mission. Achievement of this goal will provide the JCSDA partner agencies with quantitative assessments of the impacts of proposed advanced instruments on environmental analyses and prediction systems.

JCSDA Research and Development Priorities



Research and Development Priority 1: Improve Radiative Transfer Models

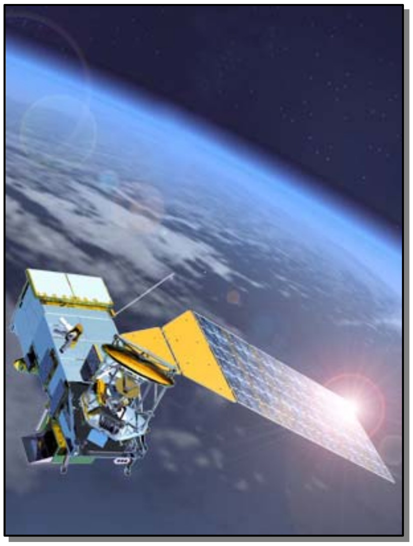
Many satellite instruments measure the radiation emitted or reflected from the Earth at different spectral wavelengths. These observations—generally referred to as radiances—contain information about the Earth's surface and atmosphere. Environmental models predict important variables describing the state of the Earth's surface and atmosphere. To be used as input to prediction models, satellite radiances must be related to the variables of the models. Radiative transfer calculations translate the satellite measurements to the model predicted variables.

Current radiative transfer models are quite accurate at calculating radiances for clear atmospheric conditions. As a result, enormous strides have been made in assimilating satellite observations of the clear atmosphere, providing data on atmospheric temperatures and moisture. Radiances affected by clouds, precipitation, or the surface are much more difficult to model, and these radiances are not currently assimilated.

Due to the burgeoning amount of high spatial, spectral, and temporal resolution observations from space, radiative transfer models will have to run faster to meet forecast model time constraints.

The JCSDA is a leader in the development of the radiative transfer models needed to assimilate satellite observations of the Earth in environmental analysis and prediction models. The JCSDA will:

- **Develop a fast, next generation Community Radiative Transfer Model (CRTM) that will have capabilities to model radiative effects of:**
  - **Additional minor atmospheric components such as carbon dioxide, methane, carbon monoxide, and aerosols. As radiative transfer models become more accurate, effects of variations in these minor components could affect satellite radiances.**
  - **Cloud and precipitation particles, which cover more than 50 percent of the Earth**
  - **The emissivity and reflectivity properties of the Earth's surface. Such a capability would enable not only assimilation of more information about the Earth's surface but also atmospheric radiances affected by radiation emanating from the surface**



Research and Development Priority 2: Prepare for Use of Advanced Instruments with Enhanced Capabilities

A major activity of the JCSDA will be the development of the methodologies and associated software and hardware tools for assimilating the data from the next generation of advanced satellite instruments. These instruments will be flying on NOAA, NASA and DoD satellites, as well as the satellites of the Global Earth Observing System of Systems (GEOSS). The large number of advanced sensors—including hyperspectral sounders, Global Positioning System (GPS) Radio Occultation, and active instruments, such as radars and lidars—will provide environmental data at spatial, temporal, and instrumental resolutions never before achieved. The data streams will contain five orders of magnitude more data than today's satellites. Assimilating the information from these sensors poses significant challenges, but potential benefits to environmental modeling are enormous.

A key performance measure for the JCSDA will be a decrease in the time required to develop and transfer the assimilation technology for each new instrument to NOAA, NASA, and DoD for operational use. The development process has pre-launch and post-launch phases. Current development times range from two to seven years. Shorter development times will allow the new instruments to come on-line earlier, thus lengthening the useful life of each new instrument and speeding up the rate of forecast improvement.

To accelerate the use of data from advanced instruments, the JCSDA will:

- **Develop sensor-specific radiative transfer software for each satellite instrument**
- **Conduct Observing System Simulation Experiments (OSSEs) to evaluate the benefits of proposed instruments and to develop the assimilation systems required for new types of instruments scheduled for launch**
- **Optimize the extraction of information content from the enormous volumes of data from hyperspectral and high spatial and temporal resolution instruments**
- **Participate in instrument calibration and validation activities, using the CRTM and NWP model analyses to compare simulated radiances with observed radiances.**

Research and Development Priority 3: Advance Techniques for Assimilating Cloud and Precipitation Observations

Forecasts of precipitation and clouds are of particular public and national interest. The sensitive regions where numerical forecasts tend to be most influenced by initial condition error often coincide with the presence of clouds. It is precisely these regions where much of the satellite data currently cannot be used, either because the infra-red (IR) sounders and IR and visible (VIS) imagers cannot penetrate the clouds or because the models cannot adequately assimilate cloud or precipitation information. Advances in the assimilation of satellite observations of clouds and precipitation together with improved observations of these regions will lead to more accurate predictions of clouds and precipitation and more accurate weather and visibility forecasts in general.

Techniques for assimilating clouds and precipitation are less well developed than for other observables. Many impediments must be overcome. The range of space scales for cloud and precipitation development is broad (meters to planetary), as is the range of time scales. Modeling of these processes in numerical prediction models is currently quite primitive. Observations of the interiors of clouds are not available. Radiative transfer schemes for cloudy skies remain to be fully developed. The physics of cloud and rain formation is non-linear and is difficult to simulate with the systems currently used in data assimilation. Error characteristics of observations and model predictions of clouds and precipitation are difficult to characterize. Large biases exist between cloud variables included in models and cloud variables observed by satellites.

To advance techniques for assimilating clouds and precipitation observations, the JCSDA will:

- **Develop the next generation Community Radiative Transfer Model, which will include a capability to calculate the radiative effects of cloud and precipitation particles**
- **Use satellite observations to validate the models that generate cloud and precipitation fields**
- **Determine error characteristics of satellite observations and model predictions of clouds and precipitation**
- **Develop new assimilation techniques to deal with the non-linearity of cloud/precipitation processes**
- **Exploit data from active sensors (CloudSat, CALIPSO, precipitation radars) to measure the vertical structures of clouds and precipitation**

Research and Development Priority 4: Advance Techniques for Assimilating Land Surface Observations

The land interacts with the atmosphere through exchanges of heat, moisture, radiation, and momentum. Modeling these processes is an important component of any atmospheric or climate prediction system. By observing reflected or emitted radiation at wavelengths for which the atmosphere is transparent, e.g., window channels, satellite instruments can see the surface. The magnitude and spectral distribution of the observed radiances provide information on vegetation conditions, surface temperature, snow cover, and radiative properties.

A major obstacle to the variational assimilation of observed radiances, or the land surface products derived from them, is the lack of forward and adjoint models to relate the satellite observations to the variables of the land surface model. Direct assimilation of radiances is hampered by unknown surface reflectivity and emissivity dependencies. Another barrier to progress is the long times needed to evaluate the impact of assimilating land surface data on weather and climate prediction. Because the evolution of the soil moisture properties is a very slow process, to obtain statistically valid results, models must be run for about a year, several times longer than those used to evaluate the impact of atmospheric observations. However, progress is being made to assimilate satellite observations of soil moisture into land surface models using techniques such as the Kalman Filter for the purpose of initializing climate forecasts.

To advance techniques for assimilating land surface observations, the JCSDA will:

- **Conduct an expanded program of Observing System Experiments to evaluate the impact of assimilating satellite observations of the land surface on weather prediction**
- **Develop the next generation CRTM, which will include a capability to calculate radiances in window spectral regions, accounting for land surface reflectivity and emissivity properties**
- **Develop enhanced snow products suite: snow cover, snow fraction, snow albedo, snow depth, snow water content, and snow cover temperature**
- **Develop enhanced vegetation product suite: green vegetation fraction, leaf area index, canopy temperature, soil surface temperature, and canopy roughness**
- **Investigate techniques for direct assimilation of satellite observations and derived quantities into land surface models**
- **Develop adjoint models for land surface models**

Research and Development Priority 5: Advance Techniques for Assimilating Ocean Observations

Ocean data assimilation is now a well-developed technology with applications that span timescales from synoptic scale (hurricane forecasting, marine safety, submarine operations) to El Niño forecasts and longer-term climate analyses and forecasts. Satellite observations are important for ocean surface temperature and ice concentration analyses for defining the marine surface for use in weather prediction models. Satellite observations are an important source of data for climate model forecasts and verification. Such verifications can be used not only to measure the accuracy of the models but also to improve the physical parameterizations used in the models. Finally, satellite observations also provide initial and boundary conditions for ocean mesoscale and seasonal-to-interannual climate forecasts, by providing the most abundant source of observations for defining the ocean sub-surface as well as the surface thermal structure.

The challenges confronting ocean data assimilation stem from the paucity of observational data to constrain the models and to provide estimates of errors, and from the strong negative influence of atmospheric forcing errors on estimates of the ocean state from numerical models. It is often difficult to distinguish errors and biases in a model from those associated with external forcing. Major issues still exist concerning the satellite observations of sea surface temperature, including effects of aerosols on infrared measurements and the use of observations sensitive to the ocean skin temperature to derive the ocean bulk temperature. Research on techniques for inferring sub-surface thermohaline structure from satellite altimeter measurements and assimilating that information with in situ subsurface data is another important area for improvement in synoptic and climate forecasting.

To advance techniques for assimilating ocean data, the JCSDA will:

- **Develop observational error characteristics and covariances—particularly biases, correlated errors, and errors of representativeness—for satellite observations of sea surface temperature, sea surface height, and ocean surface winds**
- **Improve (multi-sensor) sea surface temperature determinations, accounting for skin and bulk effects and with better corrections for aerosol effects**
- **Conduct Observing System Simulation Experiments to help define the observational requirements for remotely sensed surface salinity and accuracy requirements for improved sea surface temperature**

Research and Development Priority 6: Advance Techniques for Assimilating Atmospheric Chemistry Observations

Atmospheric chemistry models are increasingly important components of environmental monitoring and forecasting systems. Air quality and aerosol forecasts are an emerging priority of EPA, NOAA, and DoD, and NASA, as they undertake new efforts for modeling and prediction of the transport of tropospheric constituents. Of particular interest are pollutants and obscurations to visibility such as smoke and dust aerosols, and gases such as ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, and formaldehyde. NASA, NOAA, and DoD all have interests in stratospheric chemistry modelling, in particular, ozone photochemistry and dynamics. Satellite observations provide data on these tropospheric and stratospheric constituents as well as on greenhouse gases, such as carbon dioxide, carbon monoxide, and methane. Atmospheric chemistry models, when integrated with weather prediction and climate models, provide powerful tools for analyzing and predicting the evolution and distribution of greenhouse gases, quantifying the Earth’s carbon cycle, forecasting air quality, visibility, and UV sunburn indices, and improving weather forecasts in general.

Initial efforts in pollution and visibility forecasting focused on transporting aerosols and gaseous pollutants with the wind fields predicted by the NWP models, but efforts are also underway at some agencies to embed the chemistry within the NWP model, thereby allowing for interactive cloud/aerosol microphysics. The chemistry model simulates the photochemical reactions that the pollutants undergo during the transport process. Major difficulties arise from insufficient knowledge of source terms (location, duration, amount) for smoke, dust, and emissions of pollutants into the atmosphere, and, it is here that satellite observations have the potential to make a significant contribution. Forecasts of ozone pollution suffer from uncertain forecasts of cloudiness, which affects the solar UV radiation—a driver of ozone photochemistry—reaching the lower atmosphere. Stratospheric chemistry models included in operational NWP models are currently quite crude, with processes being highly parameterized and ozone the only chemical observation being assimilated. Derivation of greenhouse gas concentrations is a particularly challenging problem because of their low concentrations.

To advance techniques for assimilating atmospheric chemistry observations, JCSDA will:

- **Develop new products (e.g., ozone and aerosol profiles) from advanced satellite instruments and assimilate them into state-of-the-art models—that include chemical and biological processes—to forecast visibility, air quality, and UV index**
- **Develop techniques for detecting CO2, CH 4, and CO variations from hyperspectral IR instruments (e.g., Atmospheric Infrared Sounder [AIRS])**
- **Assimilate satellite observations of additional chemical species (CO2, nitrogen oxides, SO2, HF, HCl, etc.) into advanced atmospheric chemistry models**

Implementation

Administrative headquarters of the JCSDA and many of the information technology resources are currently housed in NOAA's World Weather Building in Camp Springs, MD. In 2008 the JCSDA will move to the new NOAA Center for Weather and Climate Prediction that is being constructed on the University of Maryland campus in College Park.

Architect's sketch of future NOAA Center for Weather and Climate Prediction

The NOAA/NESDIS Center for Satellite Applications and Research plays an important role in acquiring, maintaining, and justifying the core congressional funding line appropriation. The research and development (R&D) activities are performed by the partner agencies and the external research community. Each JCSDA partner contributes funding and/or "in-kind" resources to support execution of the R&D program and the related transition to operations program.

The R&D program consists of two components: Directed Research and Grants. The Directed Research Program is aimed at near-term developments, bringing them to the threshold of operational implementation. The Grants program is designed to support longer-term research and development projects. Whenever possible, projects of both programs use the JCSDA shared infrastructure components such as the CRTM to control cost and avoid redundancy, and to speed the operational implementation of successful efforts.

The Directed Research Program primarily supports development activities at the partner agencies and NOAA's cooperative institutes. It takes advantage of the in-house expertise in satellite remote sensing, radiative transfer, data assimilation, and numerical environmental models. Priorities for the program are assigned on a year-to-year basis and projects are focused on rapid research to operations transitions.

The JCSDA engages the external research community by funding longer-term projects on satellite data assimilation. Grantees are selected in a competitive process in response to a Federal Funding Opportunity (FFO) Announcement. The FFO is administered by NOAA using funding pooled by the partner agencies. Successful efforts under the FFO program are expected to graduate into the Directed Research Program and ultimately operational implementation.

While the need for scientists trained in satellite data assimilation is growing, there is no commensurate output of such scientists by the universities. Moreover, no major program exists in academia to conduct the kind of research needed to advance the long term state-of-the-art in satellite data assimilation. To address these shortcomings, the JCSDA plans to establish a center or consortium for research and training in satellite data assimilation. The center may be located at a single university, or distributed among a consortium of institutions.

Challenges

JCSDA activities will strongly influence the quality of operational environmental forecasts in the USA, as the Center provides *satellite data assimilation*, and *transition to operations* support for the key US operational data assimilation and forecasting groups. However, to achieve its goals the Center faces a number of major challenges.

To advance data assimilation science, it is imperative is to further develop operational systems to better handle the time dimension. Strategic plans amongst the partners show four dimensional variational data assimilation (4D-VAR) as a preferred method to approach this challenge. Addressing this challenge effectively requires continued careful construction amongst the partners of systems based on common infrastructure so that efforts in this very significant activity are not diluted by a diversity of uncoordinated approaches. The operational nature of the Partners' activities dictates the timescale of system changes; however, movement toward four dimensional assimilation systems, with increasing common infrastructure, remains a high priority activity.

A further challenge facing the Center is early involvement in calibration and validation of new instruments. The unique ability (and practice) of the operational Partners to monitor the performance of satellite instruments for every second of every day places them in a unique position to participate in instrument assessment soon after launch—as well as during the instrument's lifetime. This activity also facilitates early operational application of the data.

A major challenge is to gain effective engagement in the early stages of instrument design and manufacture. The utility of proposed instruments to support environmental analysis and modeling needs to be assessed by the operational agencies who are prime users of the data. Such evaluations would not only validate, or suggest changes in, instrument design but also lead to an enhanced ability by the agencies to use the data in the early stages of availability, as assessment usually requires preparation of a processing system for the data.

To overcome these challenges—especially the development of 4D-VAR systems—it is vital to upgrade the current infrastructure. Currently the operational agencies supporting the Center lag behind overseas operational agencies in computing power by a *significant factor*. This deficiency results in a reduced capability to develop and implement 4D-VAR and to rapidly transition to operations many new systems. The Center must work towards improving this capability to ensure that the full potential of US assimilation science and the spaced based observing systems can be exploited for the common good.

Appendix—JCSDA Roadmap